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LIFE Cost of Electricity, Capital and Operating Costs

T. Anklam

April 15, 2011

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Introduction

Successful commercialization of fusion energy requires economic viability as well as technical and scientific feasibility. To assess economic viability, we have conducted a pre-conceptual level evaluation of LIFE economics. Unit costs are estimated from a combination of bottom-up costs estimates, working with representative vendors, and scaled results from previous studies of fission and fusion plants. An integrated process model of a LIFE power plant was developed to integrate and optimize unit costs and calculate top level metrics such as cost of electricity and power plant capital cost. The scope of this activity was the entire power plant site (see Figure 1). Separately, a development program to deliver the required specialized equipment has been assembled.

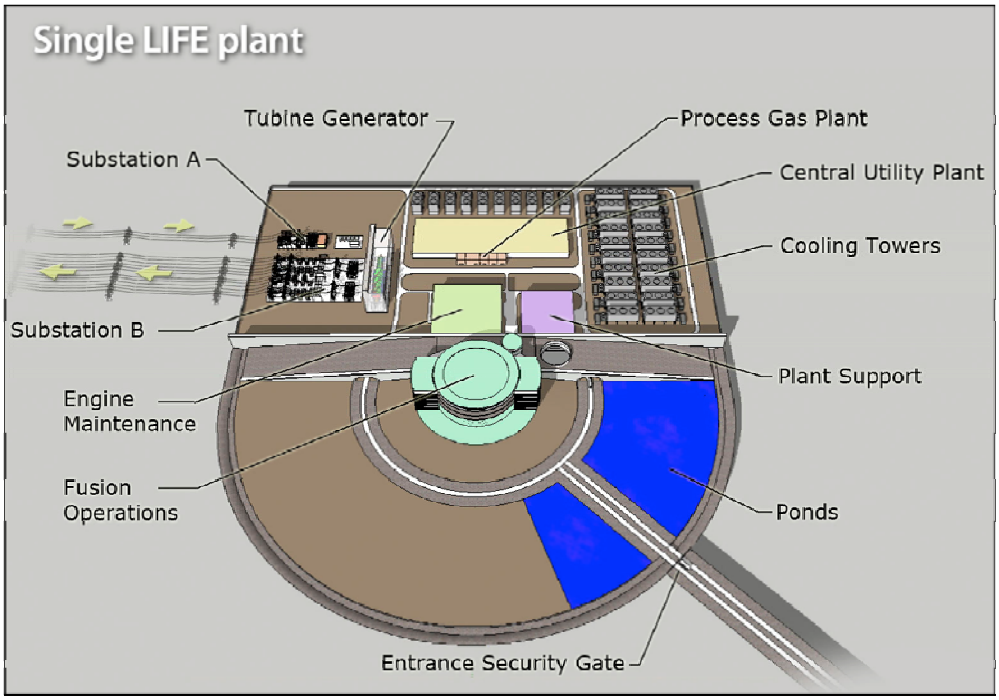

Figure 1: Key elements of the LIFE power plant site

Results show that LIFE power plant cost of electricity and plant capital cost compare favorably to estimates for new-build LWR's, coal and gas – particularly if indicative costs of carbon capture and sequestration are accounted for.

Methodology

Figure 2 summarizes the evaluation methodology.

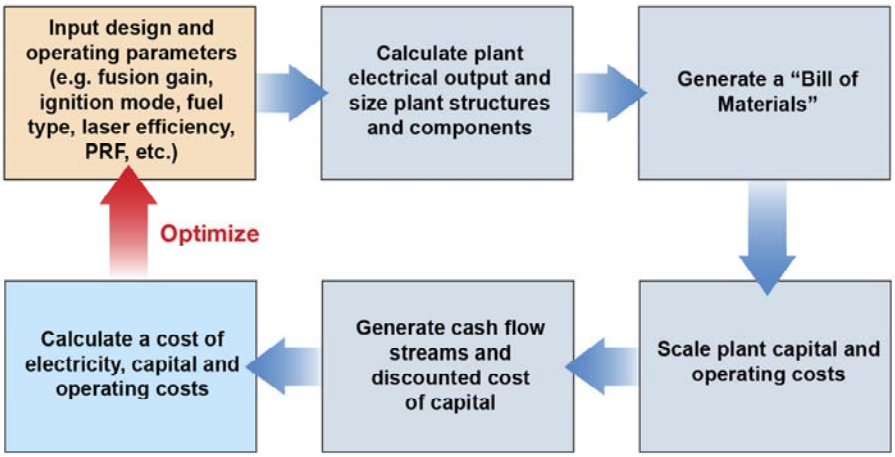

Figure2: Cost scaling flow chart.

Power plant design and operating features are input to the model. The model sizes the plant, calculates its performance and generates a bill of materials. Capital and operating costs are scaled, cash flow streams are generated and a levelized cost of electricity is calculated using the methodology described in "MIT 2009 Update to the Future of Nuclear Power" (Deutch, 2009).

Capital costs are derived by dividing the LIFE plant into ~50 cost centers. Costs for the laser system are based on a detailed bill of materials for the different subsystems. Unit costs are based on vendor quotes and NIF development and construction experience. Capital costs for the thermal plant and turbine generator system are derived from previous power plant studies, escalated to 2010 dollars and scaled to the LIFE operating point using scaling factors recommended by Delene (General Electric, 1995) (Meier W. B., 1992) (Meier W. e., 1992) (Waganer, 1992) (Delene, 1988). Decommissioning costs are taken from the Gen IV cost estimating guide (OECD, 2007). Weighted average discount rate is set to 8% (nominal); same as in the 2009 MIT study.

Fuel costs are derived from a fusion target manufacturing study (Miles, 2009). Non-fuel O&M and incremental capital costs are approximated as a percentage of overnight capital cost. Percentages are

derived from the 2009 MIT study and are taken to be the same as for a nuclear fission plant. A recent concept of operations evaluation of LIFE by an experienced A&E vendor estimated that staffing levels for a LIFE plant are somewhat lower than for a nuclear fission plant, particularly in the area of plant security. However, these reductions have yet to be integrated into the overall cost estimate.

The Plant availability allocation is set to 70% for the first LIFE plant and 92% for the N'th-of-a-Kind plant. High plant availability is enabled by the highly modular architecture of LIFE. The major elements of the laser system and the fusion chamber itself are all designed as line replaceable units (LRU's), greatly reducing plant downtime to replace failed units. For example, the laser system is designed to permit LRU change-out without interrupting fusion operations. Monte Carlo modeling of the laser system supports overall system availability >99%.

Detailed costs are rolled up into eight top-level functional elements (Figure 3). The LIFE work breakdown structure extends these eight elements to an additional 370 lower level functional elements.

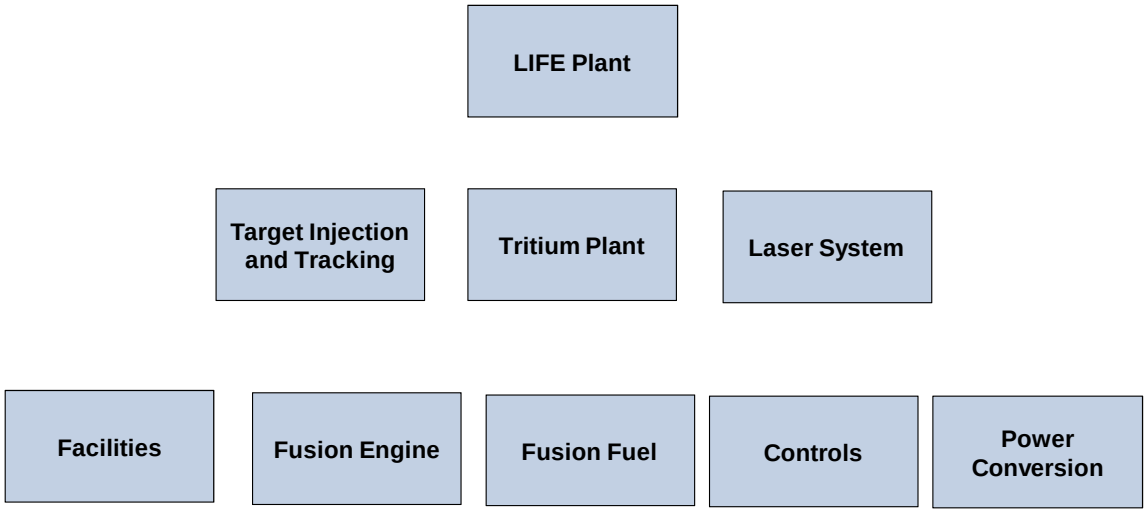

Figure 3: Top-level functional elements

Results

Figure 4 shows direct capital ($/kW$_e$) and operating costs ($/MWhr) by major functional element. The overlays are lines of constant cost of electricity. The laser is the single largest capital cost center in the plant and accounts for ~$18/MWhr in cost of electricity. Fusion target components will be purchased from an off-site factory and then assembled and filled at the factory. As a result, fusion targets appear as a large operating cost center but low capital cost (capital costs of the off-site factory are amortized and are covered in the purchase price of the targets).

Figure 5 shows the distribution between capital and operating costs at the plant level and Figure 6 shows the contributions of the different cost centers to the cost of electricity. Cost of electricity is dominated by the plant capital cost. The laser system accounts for ~30% of the cost of electricity and fusion fuel for about 20%.

Cost of electricity is estimated at about $70/MWhr for a plant size of ~900MW_e. This is in the general range of estimates for new light water reactors and somewhat less than estimates for coal and gas with carbon capture and sequestration (Simon, 2009).

The favorable comparison to light water reactors is due to several factors that compensate for the additional cost of the LIFE laser system. First, LIFE operates at a higher temperature than a light water reactor, so thermal efficiency will be higher (44% vs 32%). The second factor is that, because a fusion power plant has a lower source term than fission, accident analysis shows that safety class structures and systems aren't required.

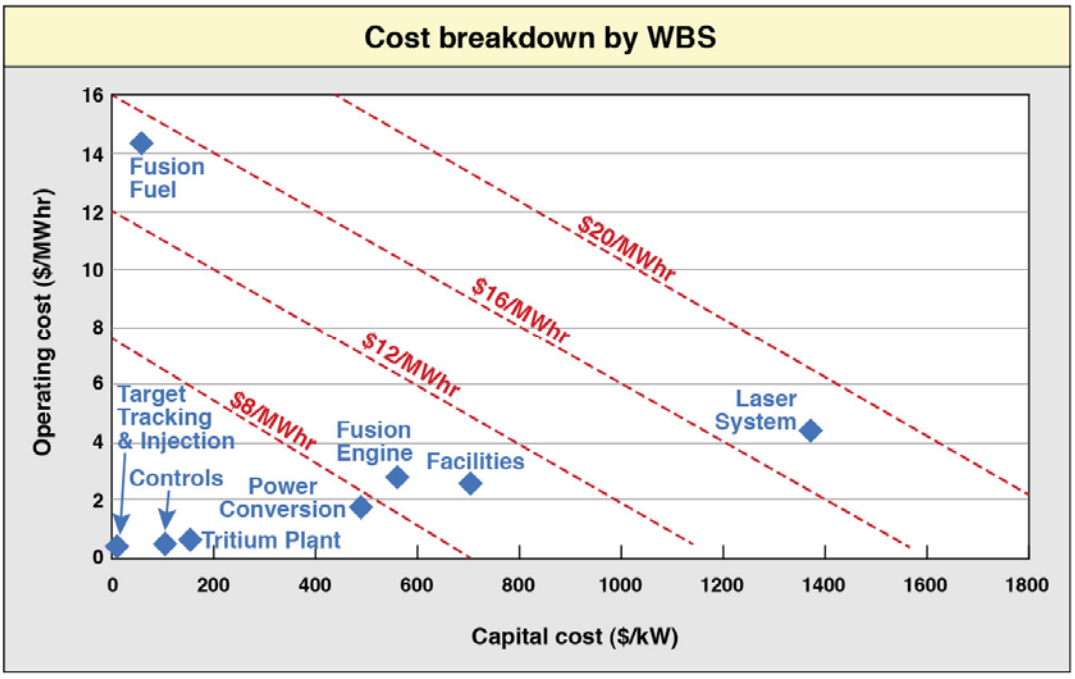

Figure 4: Capital and operating costs by major cost center.

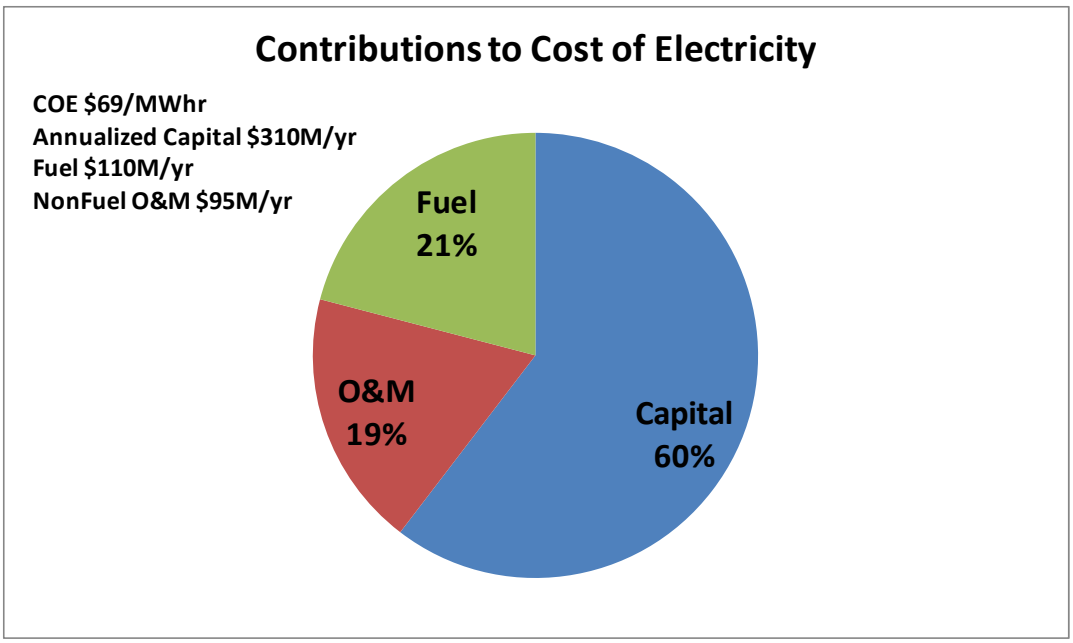

Figure 5: Contributions to cost of electricity.

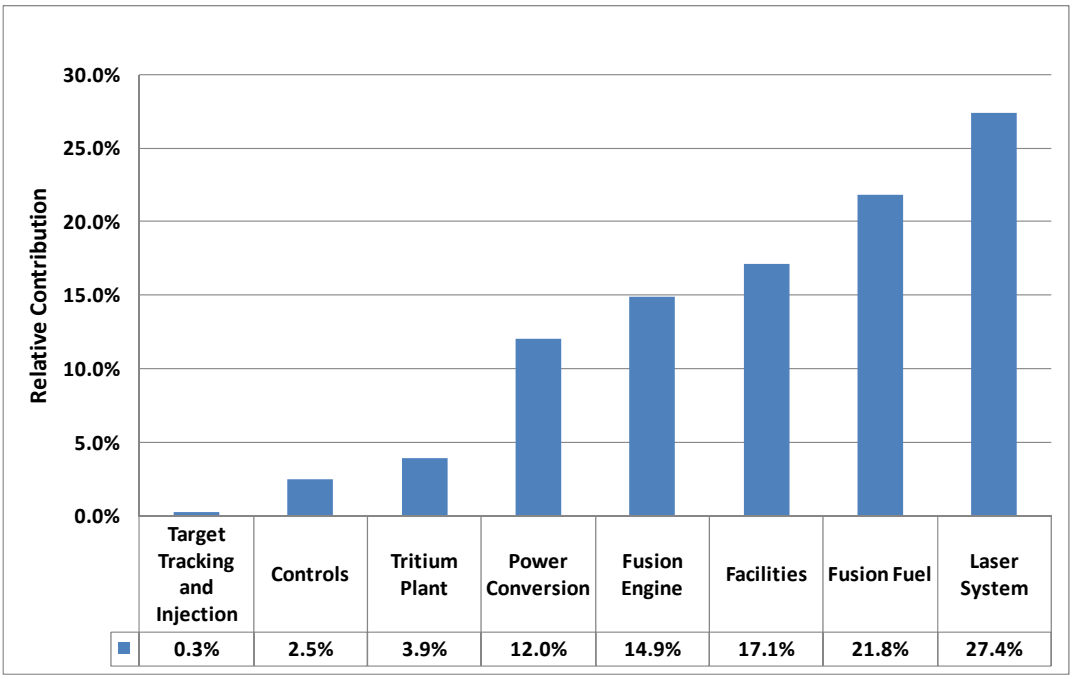

Figure 6: Contribution of different cost centers to cost of electricity.

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